

**Carderock Division**  
**Naval Surface Warfare Center**

West Bethesda, MD 20817-5700

---

**NSWCCD-TR-2000/003+CR** 20 November 1999

Materials, Structures and Survivability Directorate

Technical Report

**High Thermal Conductivity Composite Structures**

by

John Bootle

XC Associates, Inc

Berlin, New York



20000718 079

---

Approved for public release; Distribution is unlimited

---

**DTIC QUALITY INSPECTED 4**

**Carderock Division**  
**Naval Surface Warfare Center**

West Bethesda, MD 20817-5700

---

**NSWCCD-TR-2000/003+CR** 20 November 1999

Materials, Structures and Survivability Directorate

Technical Report

**High Thermal Conductivity Composite Structures**

by

John Bootle

XC Associates, Inc

Berlin, New York



---

Approved for public release; Distribution is unlimited

---

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 20 November 1999	3. REPORT TYPE AND DATES COVERED Final May - Nov 1999		
4. TITLE AND SUBTITLE High Thermal Conductivity Composite Structures		5. FUNDING NUMBERS Contract number N00167-99-C-0047		
6. AUTHOR(S) John Bootle				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) XC ASSOCIATES, INC 28 SOUTH MAIN STREET BERLIN, NY 12022		8. PERFORMING ORGANIZATION REPORT NUMBER 1000-0282		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NAVAL SURFACE WARFARE CENTER CARDEROCK DIVISION (CODE 681) 9500 MACARTHUR BOULEVARD WEST BETHESDA, MD 20817-5700		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NSWCCD-TR-2000/003+CR		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  The work accomplished in this SBIR project demonstrated that the addition of boron nitride (BN) powder to a composite laminate significantly increases the through the thickness thermal conductivity (Kz) of a composite laminate. The importance of this work is that the improved Kz results in significantly lower operating temperatures for thermal applications such as composite thermal planes for advanced electronic applications and space based radiators. The advantage of this material compared to competing materials that it can be used to fabricate high strength, high thermal conductivity, relatively thin structures less than 0.050-inch thick.  Typical graphite fiber reinforced composite thermal planes have an in-plane thermal conductivity (Kx and Ky) in the range 300-650 w/m/K, based on the fiber selection. But, the relatively low Kz of a typical composite laminate significantly reduces the efficiency of the thermal plane due to the high impedance of getting heat in or out of the laminate. Finite element analysis of typical composite thermal planes shows that by increasing the Kz from about 1 w/m/K for a typical laminate to about 4 w/m/K, as achieved in this project, results in temperature reductions in the order of 30%.				
14. SUBJECT TERMS High Thermal Conductivity Composite Enhanced Kz Lightweight Thermal Planes Spacecraft Thermal Radiators			15. NUMBER OF PAGES 20	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

## Contents

CONTENTS .....	II
LIST OF FIGURES .....	III
LIST OF TABLES .....	III
ADMINISTRATIVE INFORMATION .....	IV
ACKNOWLEDGEMENTS.....	IV
1 INTRODUCTION .....	1
2 THERMAL RESULTS .....	2
3 MECHANICAL RESULTS.....	7
4 MATERIALS.....	13
5 FABRICATION METHOD .....	14
6 FUTURE WORK .....	15
7 COMMERCIALIZATION.....	15

## List of Figures

FIGURE 1. PHOTOGRAPH OF TYPICAL COMPOSITE THERMAL CORE AND COVERS FABRICATED BY XC ASSOCIATES.....	1
FIGURE 2. KZ FOR A PRESS CURED LAMINATE.....	2
FIGURE 3. KZ FOR AUTOCLAVE CURED LAMINATE.....	3
FIGURE 4. KZ FOR PRESS AND AUTOCLAVE CURED LAMINATES .....	3
FIGURE 5. Kx AND Vf VS % BN LOADING .....	4
FIGURE 6. IMPROVED PERFORMANCE OF THERMAL CORE.....	6
FIGURE 7. TENSILE MODULUS.....	8
FIGURE 8. TENSILE STRENGTH.....	8
FIGURE 9. COMPRESSION STRENGTH .....	9
FIGURE 10. SHEAR STRENGTH .....	9
FIGURE 11. LAYOUT OF SAMPLES ON 12-INCH SQUARE TEST PANEL.....	10
FIGURE 12. SAMPLE SHOWING 0% BN FILL.....	11
FIGURE 13. SAMPLE SHOWING 8% BN FILL.....	11
FIGURE 14. SAMPLE SHOWING 16% BN FILL.....	12
FIGURE 15. SAMPLE SHOWING 16% BN FILL, VIEWED WITH POLARIZED LIGHT .....	12

## List of Tables

TABLE 1. COMPARISON OF MECHANICAL PROPERTIES .....	7
TABLE 2. MATERIAL TEST SAMPLES .....	10
TABLE 3. MATERIALS USED IN PROGRAM .....	13
TABLE 4. WEIGHT OF BN ADDED TO LAMINATE.....	14
TABLE 5. COMPARISON OF MATERIAL PROPERTIES.....	16

## **Administrative information**

This final report of a Phase I Small Business Innovation Research (SBIR) program covers work conducted under contract N00167-99-C-0047, "High Thermal Conductivity Composite Structures" by XC Associates, Inc, Berlin, NY. The work demonstrated that a simple method of adding boron nitride powder increased the thermal conductivity of a composite laminate for thermal management applications. The thermal and mechanical properties of laminates were measured. This work has direct application for improved design of composite thermal planes for avionics and space applications.

Funding for the work was provided by the Ballistic Missile Defense Organization's SBIR program office. The micrograph project described in section 3.8, in addition to the SBIR scope of work, was funded directly by XC Associates.

## **Acknowledgements**

XC Associates would like to thank Albert Bertram of the Naval Surface Warfare Center and Roger Gerzeski of the Air Force Research Laboratory for their support and guidance.

Professor Ron Bucinell of Union College carried out mechanical testing.

Steve Perrucci of Union College carried out the micrographs as part of his final year project.

## 1 Introduction

The work accomplished in this SBIR project demonstrated that the addition of boron nitride (BN) powder to a composite laminate significantly increases the through-the-thickness thermal conductivity ( $K_z$ ) of a composite laminate. The importance of this work is that the improved  $K_z$  results in significantly lower operating temperatures for thermal applications such as composite thermal planes for advanced electronic applications and space based radiators. The advantage of this material compared to competing materials is that it can be used to fabricate high strength, high thermal conductivity, relatively thin structures less than 0.050-inch thick.

Typical graphite fiber reinforced composite thermal planes have an in-plane thermal conductivity ( $K_x$  and  $K_y$ ) in the range 300-650 w/m/K, based on the fiber selection. But, the relatively low  $K_z$  of a typical composite laminate significantly reduces the efficiency of the thermal plane due to the high impedance to getting heat in or out of the laminate. Finite element analysis of typical composite thermal planes shows that by increasing the  $K_z$  from about 1 w/m/K for a typical laminate to about 4 w/m/K, as achieved in this project, results in temperature reductions in the order of 30%.

This project was carried out using Amoco (now BP Amoco) K-800X fiber, prepregged using Hexcel 954-3 resin. Since the resin, rather than the fiber, dominate  $K_z$ , the improvement in  $K_z$  is expected to be applicable to any carbon fiber laminate.

A number of companies have expressed interest in the work carried out during this project and XCA is working with them to commercialize the technology.



**Figure 1. Photograph of typical composite thermal core and covers fabricated by XC Associates**

## 2 Thermal results

### 2.1 Summary

The addition of boron nitride powder, BN, to a composite laminate increased the through-the-thickness thermal conductivity,  $K_z$ . However, the addition of the BN also reduced the fiber volume fraction. Hence, there was a decline in the in-plane thermal conductivity,  $K_x$  and  $K_y$ . Finite element analysis shows the net result was an improvement in overall thermal performance as discussed in paragraph 2.8.

Samples were cured using both a press cure without bleeding resin during the cure and an autoclave cure with significant resin bleed from the laminate during cure. The results showed that the  $K_z$  of the autoclave cure laminates was significantly higher than for the press cure. The reason for this requires further work, but a preliminary explanation is that the autoclave laminate has a higher fiber volume and the BN powder was more evenly distributed within the laminate.

### 2.2 Thermal conductivity $K_z$ , press cured laminate, no resin bleed.

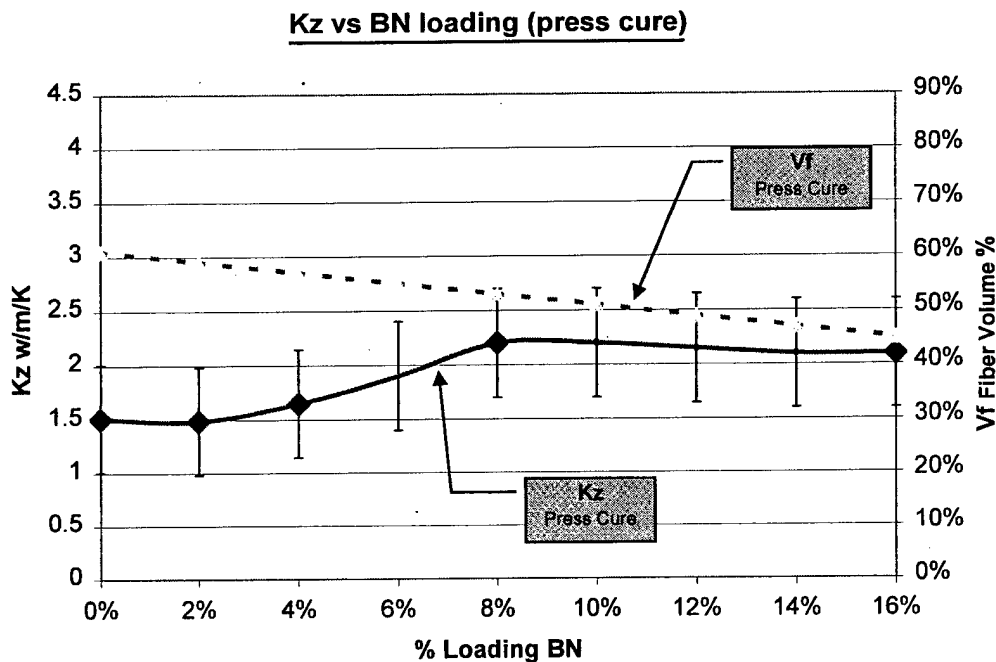
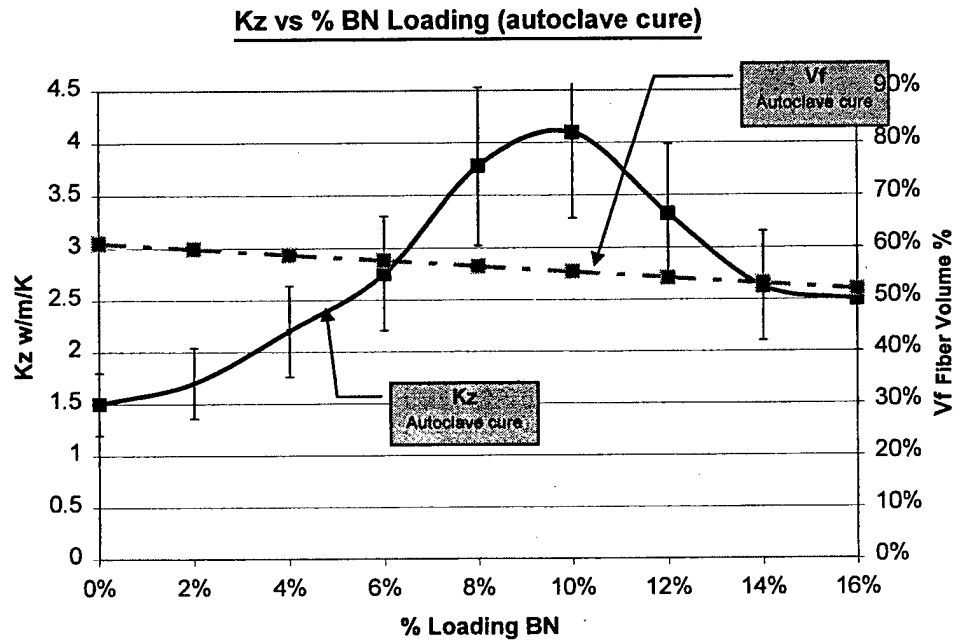
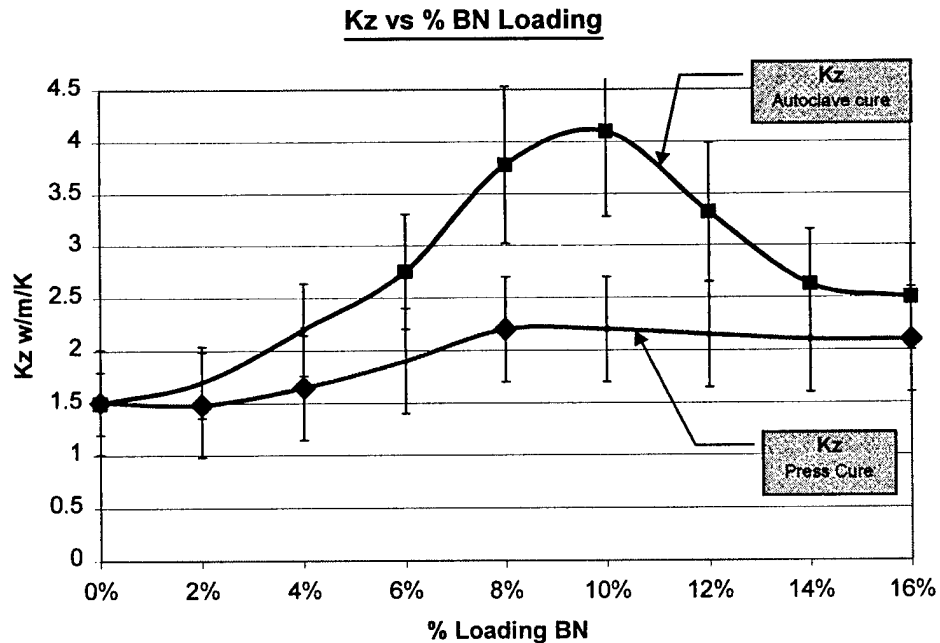


Figure 2.  $K_z$  for a press cured laminate

## 2.3

Thermal conductivity  $K_z$ , autoclave cure laminate, with resin bled.Figure 3.  $K_z$  for autoclave cured laminate

## 2.4

Graph comparing  $K_z$  for press and autoclave cured laminatesFigure 4.  $K_z$  for press and autoclave cured laminates

## 2.5 Description of graph

- 2.5.1 Laminate samples were cured using press cure during which there was very little resin bled from the laminate. During the autoclave cure cycle resin was bled from the laminate.
- 2.5.2 The fiber fraction for the unfilled laminate was calculated from the prepreg data as presented in Table 3.
- 2.5.3 The fiber fraction of the filled laminates was calculated from the ratio-cured thickness of the filled laminate to the unfilled laminate after cure.
- 2.5.4 The laser flash method was used to measure the diffusivity, specific heat and density of the samples. The thermal conductivity  $K$  was calculated as Equation 1.

$$K = \alpha \cdot \rho \cdot C_p \quad \text{Equation 1}$$

Where  $\alpha$  = Thermal diffusivity  
 $\rho$  = Density of laminate, 1.8 gr/cm<sup>3</sup> @25°C  
 $C_p$  = specific heat of laminate, 0.85 J/gr. Deg @ 25°C

## 2.6 Verification of diffusivity and fiber fraction

The graph in Figure 5 shows the measured in-plane thermal conductivity,  $K_x$ , plotted against the theoretical value calculated from Equation 2. The good agreement gives high confidence to the laser flash method and the calculated  $V_f$ .

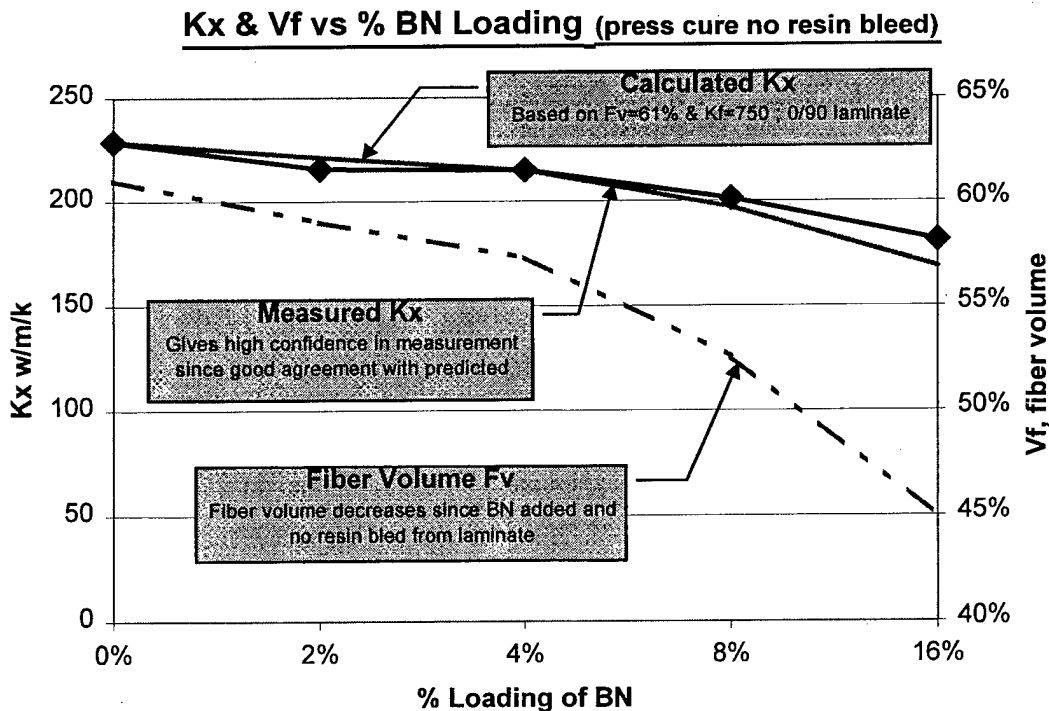


Figure 5.  $K_x$  and  $V_f$  vs % BN loading

- 2.6.1 Figure 5 also shows the variation of the measured  $K_x$  against the calculated fiber volume for the press-cured samples. (The laminate was a  $0^\circ/90^\circ$  laminate so  $K_x=K_y$ ). The fiber thermal conductivity of about 750 w/m/K was derived from data provided by Amoco.

## 2.7 Discussion of results

- 2.7.1 The laminates were fabricated by adding a predetermined weight of BN powder to each layer of the prepreg during the lay-up process. Since material was being added to the prepreg the volume increased and hence the fiber volume,  $V_f$ , decreased as more BN was added. This is important since in-plane thermal conductivity  $K_x$  and  $K_y$  is determined by the relationship

$$K_L = K_f V_f + K_m V_m \approx K_f V_f \quad \text{Equation 2}$$

The thermal conductivity of the laminate is dominated by the fiber since  $K_f \gg K_m$ . If the fibers are not orientated along the heat flow direction, the Equation is modified as

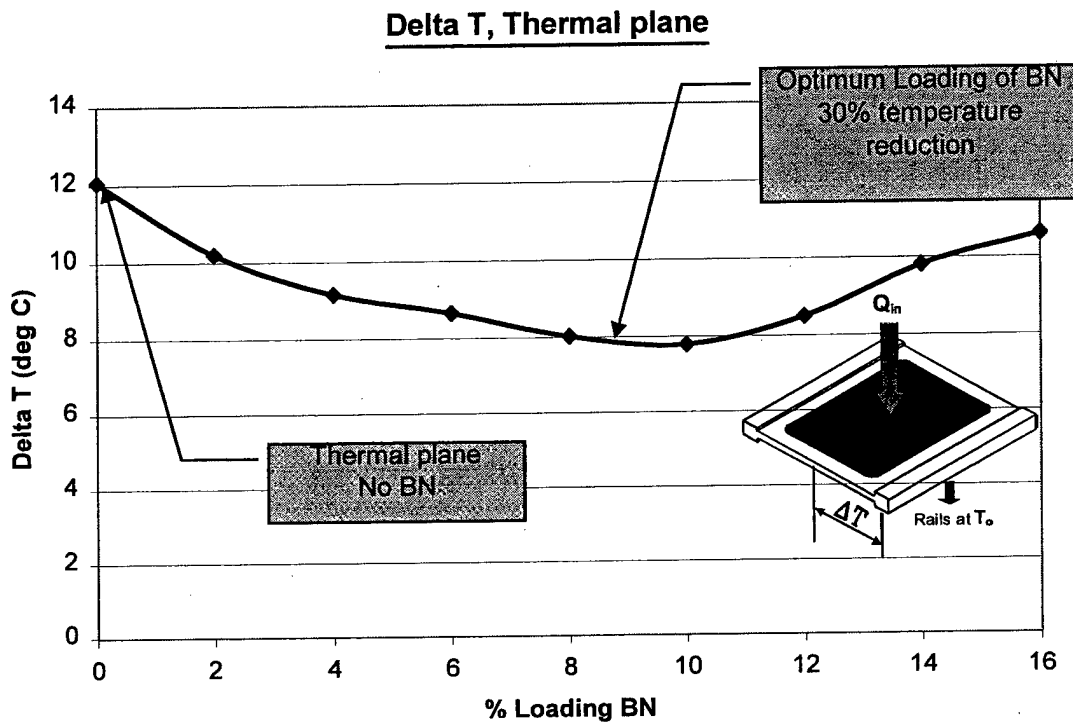
$$K_x = K_L \sin^2 \phi \quad K_y = K_L \cos^2 \phi \quad \text{Equation 3}$$

Where  $\phi$  = angle of fibers of particular ply  
 $K_f$  = Longitudinal thermal conductivity of fiber  
 $K_m$  = Thermal conductivity of matrix  
 $V_f$  = Fiber volume  
 $V_m$  = matrix fiber volume

- 2.7.2 From Equations 2 and 3 it can be seen that the thermal conductivities,  $K_x$  and  $K_y$  are controlled by the fiber conductivity since this much greater than the resin conductivity.
- 2.7.3 There was considerable scatter in the results of  $K_z$  obtained from different autoclave cured samples. The reason is that the resin bleed varied among the samples indicating this is an important variable. More work needs to be carried out in this area.
- 2.7.4 Since the resin dominates  $K_z$ , it is expected that the improvement in  $K_z$  presented above will also be applicable to laminates fabricated from other fibers.
- 2.7.5 A preliminary investigation based on two samples showed that larger particle sizes resulted in less improvement in  $K_z$ . The effect of smaller particle sizes needs to be more completely investigated.

## 2.8 Practical importance of the results

Using the measured  $K_z$  results from Figure 3, and calculating the corresponding  $K_x$  and  $K_y$  (from Equations 2 and 3), the temperature of a typical SEM-E thermal plane was calculated. The results showed that the addition of 8%-10% BN to a laminate results in a 30% temperature reduction. This analysis assumed a typical SEM-E heatsink loaded with 65 watts of heat applied uniformly across the center of the heatsink while the rails were maintained at temperature  $T_0$ . A graph of the temperature difference  $\Delta T$  is presented in Figure 6.



**Figure 6. Improved performance of thermal core**

### 3 Mechanical results

#### 3.1 Summary of mechanical properties

**Table 1. Comparison of mechanical properties**

Property	Al-Be HIP'd AM162H	Aluminum 6061-T6	Composite K-800X / 954-3 0/90 laminate
Density lb/in <sup>3</sup>	0.076	0.098	0.065
Thermal conductivity w/m/K	K <sub>x</sub> = 210 K <sub>y</sub> = 210 K <sub>z</sub> = 210	K <sub>x</sub> = 187 K <sub>y</sub> = 187 K <sub>z</sub> = 187	K <sub>x</sub> = 220 K <sub>y</sub> = 220 K <sub>z</sub> = 4
Modulus of Elasticity Msi	E = 28  G n/a	E = 10  G = 3.8	E <sub>x</sub> = 22 E <sub>y</sub> = 22 G = 4.7
Tensile Strength ksi	S <sub>x</sub> = S <sub>y</sub> = 28	S <sub>x</sub> = S <sub>y</sub> = 37	F <sub>x</sub> = 42 K <sub>y</sub> = 42

- 3.1.1 The results presented in Table 1 are for a 0/90 laminate fabricated from K-800X/954-3 laminate filled with 8% BN.
- 3.1.2 Varying the fiber type and orientation, as shown in Equations 2 and 3 can optimize the values for thermal conductivities K<sub>x</sub> and K<sub>y</sub>. Typical values for K<sub>x</sub> of 290- 530 w/m/K may be achieved using K13C2U, K-800X, or K-1100 respectively.
- 3.1.3 Stiffness and strength of the laminate are also determined by the fiber orientation.
- 3.1.4 The results of mechanical testing carried out on the press cure laminates are presented on the following pages.

### 3.2 Tensile modulus

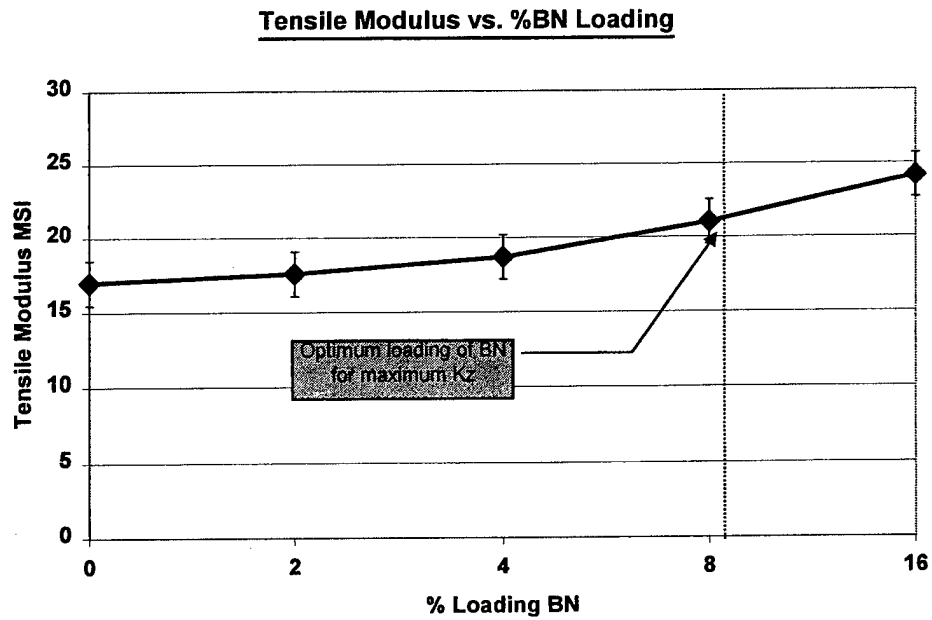


Figure 7. Tensile modulus

### 3.3 Tensile strength

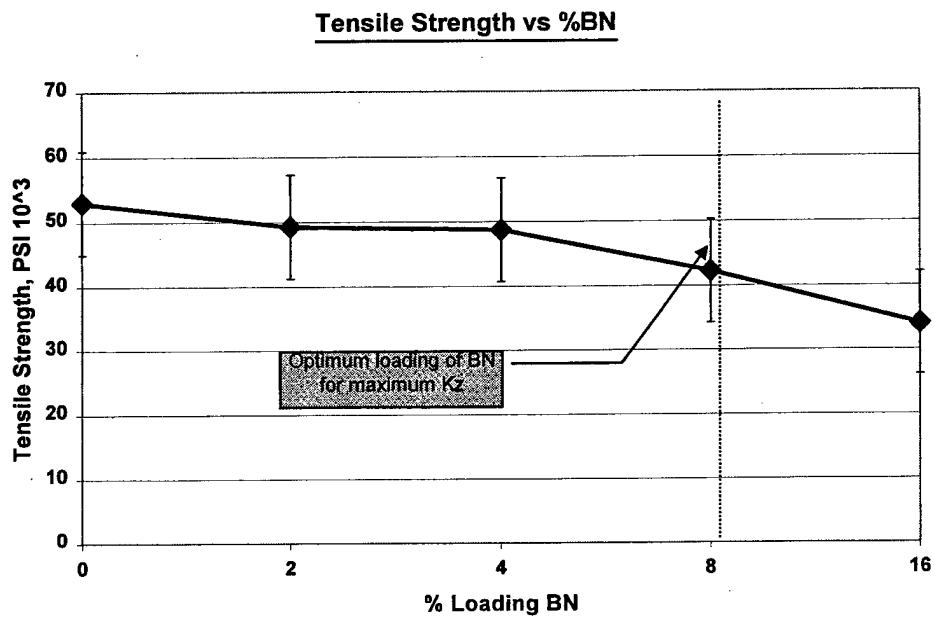


Figure 8. Tensile strength

### 3.4 Compression strength

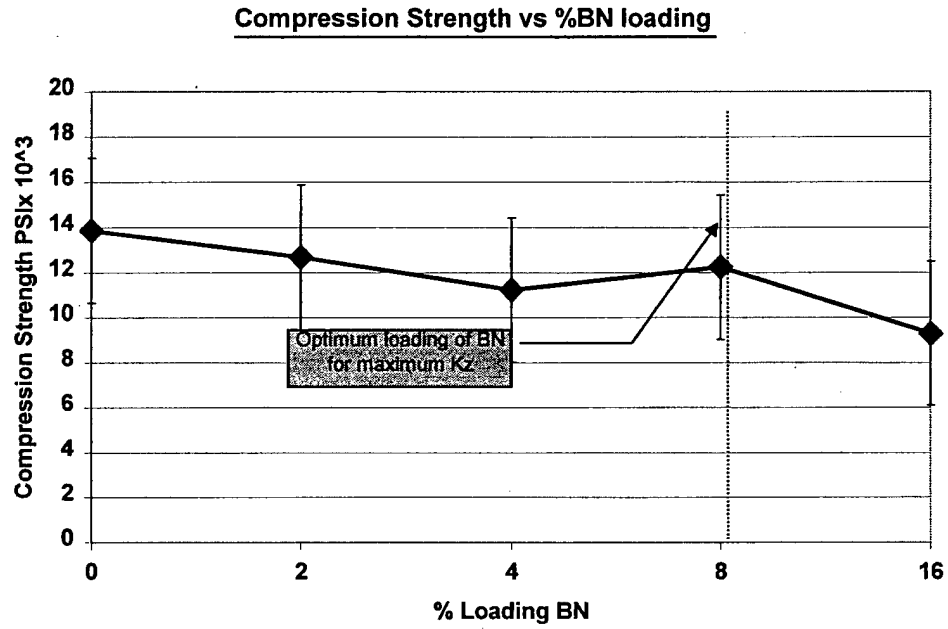


Figure 9. Compression strength

### 3.5 Shear strength

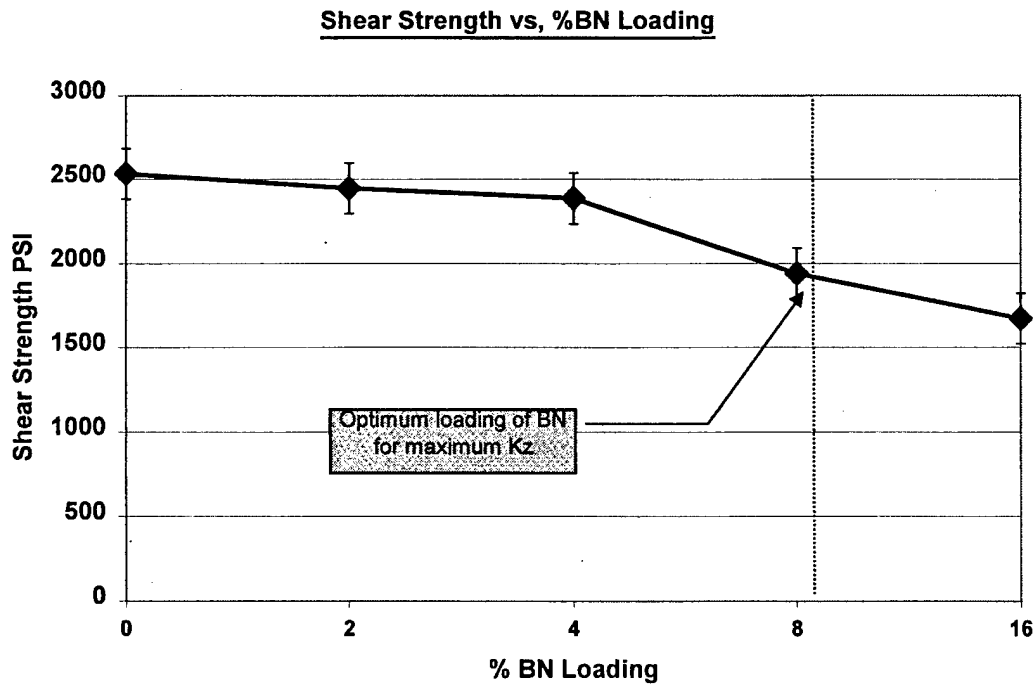


Figure 10. Shear strength

### 3.6 Discussion of mechanical results

- 3.6.1 The mechanical results indicate that the addition of BN powder reduces the laminate strength. This is expected since the addition of BN reduced the fiber volume percentage of the laminate. The measured strength of the laminate presented in Table 1 compares the strength of the laminate loaded with 8% BN compared to typical metals. Using the method of fabrication described in paragraph 5, Fabrication method, it is straightforward to only add BN to the areas with high thermal inputs and hence, achieve the highest structural strength.
- 3.6.2 We expect the mechanical strength to be related to the BN and resin volume percentages, therefore we would expect some variation between press and autoclave cure. This will be investigated in future work.
- 3.6.3 The tensile modulus increases with the addition of BN powder (see Figure 7. Tensile modulus). This result is contrary to our expectation but may be explained by the fact that the mixture of BN and resin has a higher stiffness than resin alone.

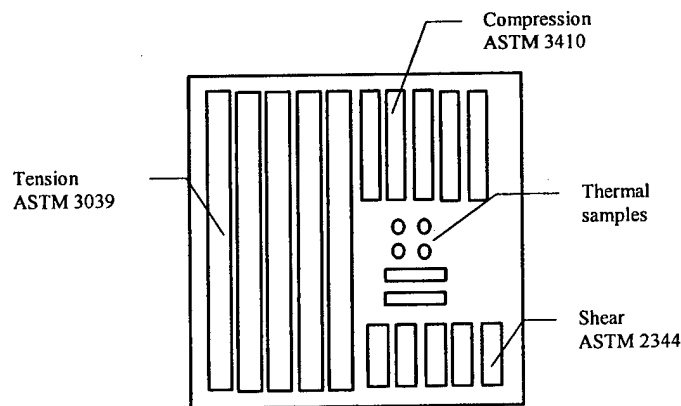
### 3.7 Mechanical test samples

- 3.7.1 The following tests were used to characterize the laminate; mechanical tests were only carried out on the press-cured samples.

**Table 2. Material test samples**

Test	ASTM	Comment
Tension	ASTM D 3039	5 test coupons from each sample
Short beam shear	ASTM D 2344	5 test coupons from each sample
Compression	ASTM D 3410	5 test coupons from each sample

- 3.7.2 The test samples were cut from a 12-inch x 12-inch x 0.1-inch thick laminate as shown in Figure 11.



**Figure 11. Layout of samples on 12-inch square test panel**

### 3.8 Microscopic

- 3.8.1 The microscopic analysis of the samples is an on-going final year project being carried out at Union College. The objective of the work is to determine the distribution of the BN powder within the laminate. Data from these micrographs will be used in further work to develop a theoretical model of heat flow through the laminate.
- 3.8.2 The results presented here are for the press cured laminates; micrographs of the autoclave samples will be presented in a later report.
- 3.8.3 Samples were polished, then examined under a microscope to determine the location of the fibers, location of the BN, and the void content. The photographs of the micro sections are presented below.

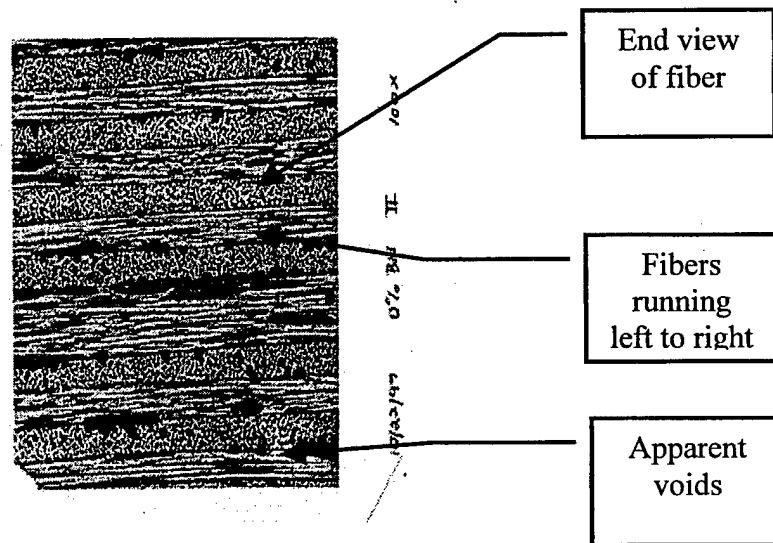


Figure 12. Sample showing 0% BN fill

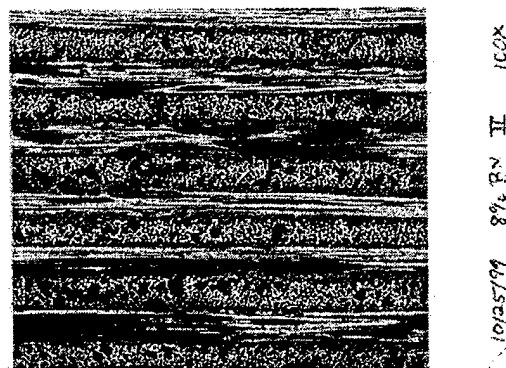
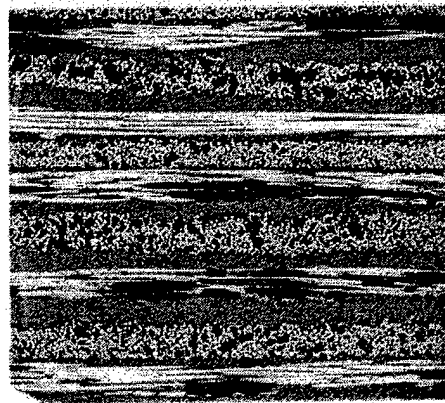
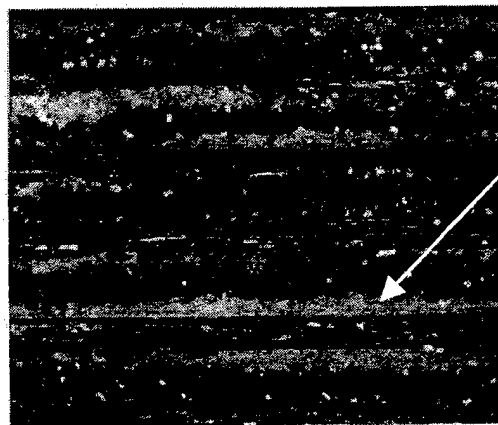


Figure 13. Sample showing 8% BN fill



**Figure 14. Sample showing 16% BN fill**



**Figure 15. Sample showing 16% BN fill, viewed with polarized light**

#### 3.8.4 Discussion of results

3.8.4.1 The reason we have referred to apparent voids in Figure 12 is due to difficulty encountered while polishing the samples caused by the variation in hardness and brittleness of the matrix, carbon fiber and BN. We believe that the voids are a material property rather than being caused by the polishing due to their random distribution. If polishing caused them we would have expected a more regular signature.

3.8.4.2 The next stage of the micrograph project will be to polish the autoclave cure samples and compare the results with the press cured samples. The polishing technique will

also be further refined. If the void content is higher in the press cure samples than the autoclave samples this may explain the difference in the measured Kz.

- 3.8.4.3 Each of the micro-sections indicated that the BN powder remained in a layer between the plies of material and did not flow in between the fibers. This is most clearly seen when the samples were viewed under polarized light as presented in Figure 15. The variation in thickness of the BN layer is attributed to uneven distribution of the powder during lay-up, uneven flow of the powder during cure or a combination of the two.

## 4 Materials

**Table 3. Materials used in program**

Material	Supplier	Specification
Fiber	Amoco	K-800 X
Prepreg	Hexcel	K-800X 2K/954 R/C: 33% ( by weight) FAW: 8365 G/M <sup>2</sup> Fiber Volume 61%
Boron Nitride	Advanced Ceramics	Polar Therm 620

### 4.1 Material selection

- 4.1.1 The choice of K-800X fiber was based on availability and cost rather than any technical reason. Since Kz is mainly dependent on the matrix it is believed that the results presented will also apply to laminates fabricated from other fibers.
- 4.1.2 Hexcel 954-3 was chosen since it is a space qualified resin and one of the applications of this technology is to fabricate thermal management components for spacecraft.
- 4.1.3 Boron Nitride was selected as the loading material to enhance Kz for the following reasons
- It is inert and will not cause corrosion
  - Compatibility of coefficient of thermal expansion
  - Commercial availability
  - A literature survey indicated BN powder significantly improved the thermal conductivity of compression molding compounds.
  - Density and structure of BN is similar to carbon.

## 5 Fabrication method

The laminates were fabricated by simply adding a predetermined weight of BN powder to plies of prepreg during a normal lay-up process. The laminates were then cured using the Hexcel recommended cure cycle for either press or autoclave.

### 5.1 Selection of fabrication method

5.1.1 The most important reasons for selecting this method of fabrication in preference to mixing the BN with the resin prior to prepregging is because:

- It is possible to load only specific areas of laminate subject to high thermal inputs. (This is particularly important for high performance, structural applications.), and
- It is very simple to carry out, particularly in small batch fabrication, and is lower cost than having the "prepregger" blend the powder during prepreg operation.

### 5.2 Details of fabrication method

**Table 4. weight of BN added to laminate**

<b>% of BN added to laminate</b>	<b>Weight grams/in<sup>2</sup></b>
0%	0.00000
2%	0.00258
4%	0.00516
6%	0.00774
8%	0.01032
10%	0.01290
12%	0.01548
14%	0.01806
16%	0.02064

The area of each ply was calculated and the weight of BN to be added was simply calculated by multiplying the area by the weight given in Table 4.

5.2.1 A detailed description of the fabrication process is presented in US patent 5,962,348, "Method of making thermal core material and material so made", authors John Bootle and Frank Burzesi and assigned to XC Associates.

## **6 Future Work**

### **6.1**

#### **6.2 Identify programs**

XCA have identified a number of programs that are interested in enhanced thermal conductivity, composite laminates. We are working with several companies to identify programs that have particular requirements that will lead to commercialization.

#### **6.3 Computer Model**

Develop a computer model of laminates to predict the thermal and mechanical behavior. This will be a very useful tool to use as a method to analysis candidate laminates to determine the critical factors influencing thermal conductivity. Prior work by XCA and others has demonstrated the Kz is influenced by a large number of variables. It would be impractical to build physical laminates and test each candidate and the use of a computer code would greatly assist with optimization.

Preliminary work indicates that the computer code would be written as a module for use with an established finite element code such as COSMOS/M

#### **6.4 Plating**

XCA have identified plating as a significant issue for composite components. In prior work, XCA has successfully plated composite thermal cores using NiCad/Chromate with excellent adhesion that resisted 500-hour salt spray testing. However, this testing required considerable surface preparation that resulted in a 64 surface finish. XCA believes that it is possible to modify the surface treatment using a corona discharge that will result in a surface better than 32.

#### **6.5 Production method**

Once programs have been identified it will be important to develop an automated method of production that will spread the required weight of BN powder in the correct areas of the laminate.

## **7 Commercialization**

### **7.1 Commercial applications**

7.1.1 XCA plans to market the BN filled composite laminates under the name of CHS-600, CHS-800 and CHS-1100 where CHS stands for Composite HeatSinks and the number refers to the nominal value of the fiber thermal conductivity.

7.1.2 The use of high thermal conductivity, composite laminates has commercial applications where higher thermal conductivity and reduced weight are required.

- 7.1.3 This program has demonstrated that the addition of BN powder to a carbon fiber laminate increases the Kz. The graph shown in Figure 6 shows that a filled composite core is more efficient than an unfilled composite thermal core and will run at a lower temperature which is a major benefit for electronic applications. XCA is working with a number of prime contractors to provide material samples for evaluation for use in future programs.
- 7.1.4 As part of this SBIR program XCA has fabricated material samples for evaluation by Lockheed Martin, Raytheon and Johns Hopkins University Applied Physics Laboratory.
- 7.1.5 A survey indicates that the technology developed in this SBIR has specific advantages over other materials used for thermal applications. Table 5 presents a comparison of BN filled carbon fiber composite materials with typical materials used for thermal applications.

**Table 5. Comparison of material properties**

<b>Material</b>	<b>Advantage of BN filled composite</b>	<b>Comment</b>
Aluminum	<ul style="list-style-type: none"> <li>• Higher thermal conductivity than aluminum</li> <li>• Thin cross-section, typically 0.060" or less</li> <li>• Lighter weight than aluminum</li> <li>• Higher stiffness and strength than aluminum</li> <li>• Low coefficient of thermal expansion</li> </ul>	Aluminum is usually the baseline material of choice based on cost, but when high thermal performance or reduced weight is required composite offers definite advantages.
Exotic Metals Al.Be, Be.Be oxide, AlSi	<ul style="list-style-type: none"> <li>• Similar performance</li> <li>• Lower cost by molding to finished shape</li> <li>• No health hazards associated with machining</li> </ul>	These metals have advantages compared to composite for applications requiring complex shapes that cannot be molded.
Unfilled carbon fiber composite	<ul style="list-style-type: none"> <li>• Addition of BN increases the Kz without increasing the cost</li> </ul>	
TC1050	<ul style="list-style-type: none"> <li>• Greater thermal conductivity for components less than 0.10" thick</li> <li>• Higher performance for thin cores</li> <li>• Higher stiffness</li> </ul>	The mechanical properties of TC1050 are determined by the skin material, which means that the material becomes inefficient for thin components.

## 7.2 Phase II

XCA is developing a Phase II proposal with the support of a number of commercial companies who are interested in using this technology for new thermal products.

## DISTRIBUTION

	<u>Copies</u>		<u>Copies</u>
<b>DOD ACTIVITIES (CONUS)</b>		ATTN LIZ SHINN	1
ATTN R C POHANKA (CODE 332)	1	WL/MLBP BUILDING 654	
L KABACOFF (CODE 332)	1	2941 P STREET STE 1	
I MACK (CODE 312)	1	WRIGHT LABORATORY	
OFFICE OF NAVAL RESEARCH		WRIGHT PATTERSON AFB OH 45433-7750	
BALLSTON CENTRE TOWER ONE		ATTN KRIS KEARNS	1
800 N QUINCY STREET		TIA BENSON TOLLE	1
ARLINGTON VA 22217-5660		ROGER GERZESKI	1
ATTN L E SLOTER	1	WL/MLBC BUILDING 654	
STAFF SPECIALIST FOR MATERIALS		2941 P STREET STE 1	
AND STRUCTURES		AIR FORCE LABORATORY	
ODUSD(S&T)/WEAPONS SYSTEMS		WRIGHT PATTERSON AFB OH 45433-7750	
3080 DEFENSE PENTAGON		ATTN JERRY BEAM	1
WASHINGTON DC 20301-3080		WL/PRP BUILDING 18	
ATTN A CULBERTSON	1	AIR FORCE LABORATORY	
STAFF SPECIALIST, SPACE SYSTEMS		1921 SIXTH STREET STE 14	
ODUSD(S&T)/SPACE SYSTEMS		WRIGHT PATTERSON AFB OH 45433-6563	
3080 DEFENSE PENTAGON		ATTN MARY LEE GAMBONE	1
WASHINGTON DC 20301-3080		BENJI MARUYAMA	1
DEFENSE TECHNICAL		WL/MLLM BUILDING 655	
INFORMATION CENTER		2230 TENTH STREET STE 1	
8725 JOHN J KINGMAN ROAD		WRIGHT PATTERSON AFB OH 45433-7817	
SUITE 0944		ATTN W GAMMIL (PL/VSD)	1
FORT BELVOIR VA 22060-6218	1	ROBERT ACREE (PL/VSD)	1
ATTN K G BEASLEY	1	AIR FORCE RESEARCH LABORATORY	
BLDG 2044 CODE 6043		3550 ABERDEEN AVENUE SE	
CRANE DIVISION		KIRTLAND AFB NM 87117-5776	
NAVAL SURFACE WARFARE CENTER		ATTN LEE RAY	1
300 HIGHWAY 361		US ARMY SPACE AND MISSILE	
CRANE IN 47522-5001		DEFENSE COMMAND	
ATTN JERRY RUBINSKY	1	MDSTC/SMDC-TC-AC	
BLDG 2187 SUITE 2320A		P O BOX 1500	
NAVAL AIR WARFARE CENTER		HUNTSVILLE AL 35807-3801	
AIRCRAFT DIVISION		ATTN DONALD WOODBURY	1
48110 SHAW ROAD UNIT #5		(AMSRL-WT-L)	
PATUXENT RIVER MD 20670-5304		ARMY RESEARCH LABORATORY	
ATTN W R BRAUN (CODE 8222)	1	2800 POWDER MILL ROAD	
NAVAL RESEARCH LABORATORY		ADELPHI MD 20783-1145	
4555 OVERLOOK AVENUE SW		ATTN J F CRIDER (FSTC/DRXST-MTI)	1
WASHINGTON DC 20375-5355		ARMY FOREIGN SCIENCE AND	
		TECHNOLOGY CENTER	
		220 7TH STREET	
		CHARLOTTESVILLE VA 22901	

**DISTRIBUTION (Continued)**

	<u>Copies</u>		<u>Copies</u>
ATTN STEVE WAX	1	ATTN TIMOTHY KNOWLES	1
WILLIAM COBLENZ	1	ENERGY SCIENCE LABORATORIES INC	
DEFENSE ADVANCED RESEARCH		6888 NANCY RIDGE DRIVE	
PROJECTS AGENCY		SAN DIEGO CA 92121	
MATERIALS SCIENCES DIVISION			
3701 NORTH FAIRFAX DRIVE		ATTN BILL DAVIS	1
ARLINGTON VA 22203-1714		APPLIED MATERIAL TECHNOLOGIES INC	
		3611 SOUTH HARBOR BLVD	
<b>NON-DOD ACTIVITIES (CONUS)</b>		SUITE 225	
		SANTA ANA CA 92704-8928 I	
ATTN WALLACE VAUGHN (CODE 188B)	1		
NASA LANGLEY RESEARCH CENTER		ATTN JIM CALDER	1
8 WEST TAYLOR STEET		MATERIAL INNOVATIONS INC	
HAMPTON VA 23681-0001		5362 OCEANUS DRIVE UNIT A	
		HUNTINGTON BEACH CA 92649	
ATTN L NIEMEYER (CODE 547)	1		
TED SWANSON (CODE 545)	1	ATTN W C RILEY	1
DAN BUTLER (CODE 545)	1	RESEARCH OPPORTUNITIES INC	
NASA GODDARD SPACE FLIGHT CENTER		P M B 7000-67	
GREENBELT MD 20771		ROLLING HILLS ESTATES CA 90274	
ATTN AL JUHASZ (MS 301-3)	1	ATTN REX CLARIDGE (01/2220)	1
D A JAWORSKE (MS 309-1)	1	ED SILVERMAN (01/2220)	1
R SHALTENS (MS 301-3)	1	TRW ELECTRONICS AND DEFENSE	
NASA GLENN RESEARCH CENTER		ONE SPACE PARK	
21000 BROOKPARK ROAD		REDONDO BEACH CA 90278	
CLEVELAND OH 44135-3191			
		ATTN MARK VAN DEN BERGH	1
ATTN H KATZMAN (MS M2/248)	1	DWA COMPOSITE SPECIALTIES INC	
G STECKEL (MS M2/248)	1	21130 SUPERIOR STREET	
W KAO (MS M2/242)	1	CHATS WORTH CA 91311-4393	
M ASWANI (MS M4/920)	1		
THE AEROSPACE CORPORATION		ATTN SUSAN FERER	1
P O BOX 92957		(LOC SC BLDG S25 MS C343)	
LOS ANGELES CA 90009-9257		PAM BURNS	1
		(B S41 MS A305)	
ATTN JANET M SATER	1	JIM WASYNCZUK	1
MICHAEL A RIGDON	1	(LOC SC BLDG S41 MS A345)	
SCIENCE AND TECHNOLOGY DIVISION		CHRIS SCHAFER	1
INSTITUTE FOR DEFENSE ANALYSES		(BLDG S4 MS S301)	
1801 N BEAUREGARD STREET		HUGHES SPACE AND	
ALEXANDRIA VA 22311-1772		COMMUNICATIONS COMPANY	
		P O BOX 92919	
ATTN P J BIERMANN	1	LOS ANGELES CA 90009	
JOHNS HOPKINS UNIVERSITY			
APPLIED PHYSICS LABORATORY		ATTN JIM ZIMMER	1
JOHNS HOPKINS ROAD		AEROTHERM CORPORATION	
LAUREL MD 20723-8099		580 CLYDE AVENUE	
		MOUNTAIN VIEW CA 94043	
ATTN GARY WONACOTT	1		
VANGUARD COMPOSITES GROUP		ATTN DONALD L SCHMIDT	1
5550 OBERLIN DRIVE SUITE B		CARBON FIBER COMPOSITES	
SAN DIEGO CA 92121-1717		1092 LIPTON LANE	
		DAYTON OH 45430-1314	

**DISTRIBUTION (Continued)**

	<u>Copies</u>		<u>Copies</u>
ATTN K BENNER (070-01/B151)	1	ATTN SURAJ RAWAL (DC3085)	1
R D TORCZYNER (VI-30/B157)	1	LOCKHEED MARTIN ASTRONAUTICS	
LOCKHEED MARTIN MISSILES		P O BOX 179	
& SPACE COMPANY INC		DENVER CO 80201	
1111 LOCKHEED MARTIN WAY			
P O BOX 3504		ATTN D CHONG (MC S001 2700)	1
SUNNYVALE CA 94088-3504		THE BOEING COMPANY	
		P O BOX 516	
ATTN J E COONEY (M/S G-97)	1	ST LOUIS MO 63168-0516	
SCOTT PECK (M/S G-97)	1		
SPACE SYSTEMS/LORAL		ATTN S V HAYES (M/SWT-21)	1
3825 FABIAN WAY		R C VAN SICLEN (M/S WT-21)	1
PALO ALTO CA 94303		ROY COX (MIS WT-78)	1
		JOE WRIGHT (M/S SK-03)	1
ATTN GARY PATZ	1	LOCKHEED MARTIN VOUGHT SYSTEMS	
YLA INCORPORATED		CORPORATION	
2970 BAY VISTA COURT		P O BOX 650003	
BENICIA CA 94510		DALLAS TX 75265-0003	
ATTN STEVEN DROULARD	1	ATTN TIM D BURCHELL	1
CCS COMPOSITES LLC		JAMES KLETT (MS 6087 B4508))	1
2990-B BAY VISTA COURT		OAK RIDGE NATIONAL LABORATORY	
BENICIA CA 94510		P O BOX2008	
		OAK RIDGE TN 37831-6087	
ATTN TOM LUHMAN (MS 73-09)	1		
PETER RIMBOS (MS 82-97)	1	ATTN JERRY PLITE (MP 450)	1
STEVE HAHN (MS 82-97)	1	LOCKHEED MARTIN ELECTRONICS	
BOEING DEFENSE AND SPACE GROUP		AND MISSILES	
P O BOX 3999		5600 SAND LAKE ROAD	
SEATTLE WA 98124-2499		ORLANDO FL 32819-8907	
ATTN JOSEPH K WEEKS	1	ATTN JANET NICKLOY	1
THERMAL PRODUCTS INC		HARRIS CORPORATION	
2257 SOUTH 1100 EAST SUITE 2C		GOVERNMENT AEROSPACE SYSTEMS DIV	
SALT LAKE CITY UT 84106-2379		P O BOX 94000	
		MELBOURNE FL 32902-9400	
ATTN J C WITHERS	1		
MER CORPORATION		ATTN R A MAYOR (MAIL STOP 706-24)	1
7960 S KOLB ROAD		PRATT & WHITNEY	
TUCSON AZ 85706		P O BOX 109600	
		WEST PALM BEACH FL 33410-9600	
ATTN D LEMON	1		
H W DAVIS	1	ATTN CHRIS SPRAGG	3
JOHN VALDEZ	1	GERRY WARD	1
BALL AEROSPACE SYSTEMS DIVISION		GIRISH DESHPANDE	1
P O BOX 1062		BPAMOCO POLYMERS INC	
BOULDER CO 80306		4500 MCGINNIS FERRY ROAD	
		ALPHARETTA GA 30005-3914	
ATTN MIKE DEAN	1		
TECMATION ASSOCIATES LTD		ATTN TERRY WALKER	1
1620 LINDEN LAKE ROAD		HONEYWELL INC	
FORT COLLINS CO 80524-2253		AIRCRAFT LANDING SYSTEMS	
		3520 WESTMOOR STREET	
		SOUTH BEND IN 46628	

## DISTRIBUTION (Continued)

	<u>Copies</u>		<u>Copies</u>
ATTN D D EDIE CTR FOR ADV ENGR FIBERS AND FILMS 301 RHODES ENGR RESEARCH CENTER CLEMSON UNIVERSITY CLEMSON SC 29634-0910	1	ATTN WALT ROSEN MATERIALS SCIENCES CORPORATION 500 OFFICE CENTER DRIVE SUITE 250 FORT WASHINGTON PA 19034	1
ATTN HENRY RACK DEPARTMENT OF CERAMIC ENGINEERING OLIN HALL CLEMSON UNIVERSITY CLEMSON SC 29634-0907	1	ATTN ILAN GOLECKI HONEYWELL INTERNATIONAL P O BOX 1021 101 COLUMBIA ROAD MORRISTOWN NJ 07962-1021	1
ATTN TIM WHALEN LOCKHEED MARTIN FEDERAL SYSTEMS 9500 GODWIN DRIVE MANASSAS VA 22110	1	ATTN JIM STRIFE UNITED TECHNOLOGIES RESEARCH CTR 411 SILVER LANE EAST HARTFORD CT 06108	1
ATTN BEN RODINI NICK TETI SWALES AEROSPACE 5050 POWDER MILL ROAD BELTSVILLE MD 20705	1 1	ATTN JAMES A CORNIE MMCC INC 101 CLEMATIS AVENUE #1 WALTHAM MA 02453-7012	1
ATTN J D GARDNER (MS 339) NORTHROP GRUMMAN ELECTRONIC SENSORS AND SYSTEMS DIVISION P O BOX 746 BALTIMORE MD 21203	1	ATTN BOB BURNS FIBER MATERIALS INC BIDDEFORD INDUSTRIAL PARK 5 MORIN STREET BIDDEFORD ME 04005	1
ATTN GERRY LAVIN E I DUPONT DENEMOURS & COMPANY CENTRAL RESEARCH AND DEV EXPERIMENTAL STATION P O BOX 80302 WILMINGTON DE 19880-0302	1	ATTN BILL BERG VERMONT COMPOSITES INC 139 SHIELDS DRIVE BENNINGTON VT 05201	1
ATTN CARL ZWEBEN COMPOSITE CONSULTANT 62 ARLINGTON ROAD DEVON PA 19333-7786	1	ATTN JOHN BOOTLE XC ASSOCIATES 28 SOUTH MAIN STREET BERLIN NY 12022	10
ATTN K BUESKING/B SULLIVAN MATERIALS RESEARCH & DESIGN INC 1024 E LANCASTER AVENUE ROSEMONT PA 19010	1	ATTN JEFF GUTHRIE ITT RESEARCH INSTITUTE 201 MILL STREET ROME NY 13440	1
ATTN TOM CASSIN MARK MONTESANO K TECHNOLOGY CORPORATION 500 OFFICE CENTER DRIVE SUITE 250 FORT WASHINGTON PA 19034	1 1	ATTN CARL IRWIN NRCCE WEST VIRGINIA UNIVERSITY P O BOX 6064 MORGANTOWN WV 26506	1
		ATTN RALPH D MAIER CAST METAL COMPOSITES INC 4440 WARRENSVILLE CENTER ROAD WARRENSVILLE OH 44128	1

**DISTRIBUTION (Continued)**

	<u>Copies</u>		<u>Copies</u>
ATTN STEVE YOUNG	1	<b>INTERNAL DISTRIBUTION</b>	
GENERAL DYNAMICS INFORMATION		CODE 011 (J CORRADO)	1
SYSTEMS		CODE 0112 (J BARKYOUNB)	1
MAIL STOP BLCS1S		CODE 011S (W MESSICK)	1
8800 QUEEN AVENUE SOUTH		CODE 601 (A G S MORTON)	1
BLOOMINGTON MN 55431		CODE 603 (J CAVALLARO)	1
		CODE 6501 (E CAMPONESCHI)	1
		CODE 68 (W D SUDDUTH)	1
		CODE 681 (A BERTRAM)	10
		CODE 681 (J LEE)	1
		CODE 681 (J FOLTZ)	1
		CODE 681 (M OPEKA)	1
		CODE 3442 (TIC)	1